Using NMR to Validate First-Principles Granular Flow Equations

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Granular flow and fluidized-bed properties in reduced gravity and interstitial gas pressure will be important for processing, storage, and other applications during lunar and Martian missions. However, current engineering practice for granular flows is based on correlations of Earth-gravity data and so cannot be extrapolated with any certainty to reduced gravity. An alternative path is to use experiments to validate granular flow equations derived from fundamental physical principles, in which the acceleration of gravity appears as an explicit input parameter. To the extent that this is possible, reasonable predictions for reduced gravity granular systems can be made, although it will remain necessary to test the predictions in actual microgravity experiments. We are engaged in a program of experiments to build up detailed pictures of dense, three-dimensional granular systems in Earth gravity using NMR methods combining MRI, PFG-NMR, and hyperpolarized-gas NMR. Using these methods we are able to measure density profiles, and grain as well as gas motions over millisecond to second time scales. We will describe our studies of three granular flow systems: the vibrofluidized bed, gravity-driven flow through a vertical channel, and the bubbling gas-fluidized bed. For the vibrofluidized bed, we have already made successful contact with first-principles hydrodynamic theory in which gravity appears as an input parameter [C. Huan, et al., Phys. Rev. E 69, 041302 (2004)]. Our work on the other two systems is at a preliminary stage.